

4. *On some INTRUSIVE ROCKS in the NEIGHBOURHOOD of ESKDALE (CUMBERLAND).* By ARTHUR RICHARD DWERRYHOUSE, D.Sc., F.G.S. (Read November 18th, 1908.)

[PLATE III—MICROSCOPE-SECTIONS.]

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I. INTRODUCTION.

CHIEF amongst the group of intrusive rocks which it is my purpose to describe is the granite of Eskdale and Wasdale Head, which possesses petrological characters of peculiar theoretical interest; but I shall also deal with certain minor intrusions near the foot of Peers Gill in Upper Wasdale, and with several groups of dykes which have been usually thought to be associated with the Eskdale Granite, but appear to me to have had a separate origin at a period remote from that of the intrusion of the granite.

II. THE ESKDALE GRANITE.

The granite comes to the surface in two exposures. The larger and more southerly of these occupies an extensive tract of country in Eskdale and Mitredale, and extends southwards as far as Bootle Fell, while it reaches to within a mile of the sea in the neighbourhood of Ravenglass.

The smaller outcrop lies in the floor of Upper Wasdale and extends from Down-in-the-Dale, beneath the hotel at Wasdale Head, and up the valley to about half a mile above Burnthwaite Farm. The larger outcrop has a total length of some 12 miles and a breadth of 4 at its widest part, while the smaller mass measures about 1 mile in length by half a mile in breadth, and is roughly elliptical in form.

The rock is mentioned by Clifton Ward in a paper entitled 'The Granitic, Granitoid, & Associated Metamorphic Rocks of the Lake District,'¹ and also in the Geological Survey memoir on the district.² In the former paper Ward describes the granite as being the ultimate product of the metamorphism of the rocks of the Borrowdale Volcanic Series. This view is, of course, unsupported by modern work, and indeed the composition of the rock itself is inconsistent with such a mode of origin.

¹ Quart. Journ. Geol. Soc. vol. xxxi (1875) pp. 568-602 & vol. xxxii (1876) pp. 1-34.

² 'The Geology of the Northern Part of the English Lake District' Mem. Geol. Surv. 1876.

Reference is also made to the Eskdale Granite by Mr. Harker,¹ who classes it with the biotite-granites, and by Dr. Teall in his 'British Petrography' 1888, pp. 322-23, the latter describing the rock as follows:—

'The ferromagnesian constituent (generally dark mica) plays a very subordinate part in the composition of the rock the quartz is frequently idiomorphic with respect to the felspar, or else the two minerals exhibit a tendency to micropegmatitic structure. Plagioclase is sparingly represented, and the quartz is sometimes seen to be idiomorphic with respect to it; a somewhat unusual feature.'

The specimen thus described, although it can be accurately matched from at least two parts of the outcrop, can hardly be considered typical of the Eskdale Granite, which is essentially a muscovite-bearing rock and in which a felspar consisting of an intergrowth of orthoclase and oligoclase is extremely common. The numerous varieties of this granite will be presently described.

Field-Relations of the Granite.

The granite is intrusive in the lavas and ashes of the Borrowdale Series, and its line of junction with these rocks is well seen at intervals along its north-western, northern, south-eastern, and eastern margins; but to the westward both the Borrowdale rocks and the granite are covered unconformably by the Trias (St. Bees Sandstone).

For a distance of about half a mile, from the foot of Wastwater to Eastwaite Farm, the granite is in contact with the Buttermere and Ennerdale Granophyre recently described by Mr. R. H. Rastall.² From the foot of Wastwater the boundary runs due south up the steep slope by Pens End on to the shoulder of Whin Rigg, the junction being for some distance a faulted one, and the fault-plane being occupied by a vein of ironstone. The line of fault cannot, however, be far from the edge of the intrusion, as the natural boundary comes in on the crest of the hill, and in several places on the slope the fine-grained marginal varieties of the granite, which will be more fully described hereafter, are to be seen.

The floor of Mitredale is occupied by the granite, and in Robin Gill, a tributary of the Mite, the junction of the granite and the Borrowdale rocks is seen dipping at a low angle northwards. The granite becomes increasingly finer in texture as the margin is approached, and undergoes at the same time a considerable change in chemical composition. The Borrowdale rocks are much altered, and in some places approach the condition of a mica-schist.

From Mitredale the line of junction passes along Black Gill over White Moss to Brown Band, and turns northwards by Acre Hows and Eskdale Moor to the shores of Burnmoor Tarn. It then crosses Hardrigg Gill at 1100 feet above O.D., the junction being visible

¹ 'Petrology for Students' 3rd ed. (1902) p. 37.

² Quart. Journ. Geol. Soc. vol. lxii (1906) pp. 253-73.

in the small gorge at the head of the cascade, about 10 yards below the point where a small tributary joins the stream on its left bank. Close to the junction the granite is white with a greenish tinge, is extremely fine-grained, and contains 96·16 per cent. of silica. Some 10 yards farther from the margin it assumes a pink colour, and is similar in texture to the finer specimens from Robin Gill. Specimens of the actual junction were collected, and a junction-breccia, consisting of fragments of Borrowdale lava in a granite-matrix, occurred as boulders in the bed of the stream.

In Oliver Gill the junction occurs at about 1150 feet, the actual contact being obscured by boulders. The granite and the Borrowdale rocks may, however, be traced to within 15 yards of each other, the former showing marginal features. From Oliver Gill the boundary rises considerably, and on Blaebury How is at a height of 1350 feet. The granite is fine-grained and white; the fine-grained pink variety comes in farther from the margin and extends down to 1150 feet, gradually passing into the normal granite at lower levels.

The edge of the granite now passes along the flanks of Great How and gradually assumes a lower level, until at Whinscales Sheepfold, near the head of Brockshaw Beck, it is at a height of 1200 feet. At this point the junction dips at an angle of about 45° eastwards. The marginal zone is unusually narrow at this point, the rock in contact with the granite being a bedded ash. There is a well-marked junction-breccia here, the fragments of Borrowdale Ash between the granite-veins being remarkably angular and showing no signs of absorption (100 & 101).¹

Stony Tarn lies in a hollow in the Borrowdale rocks, the granite-boundary sweeping round to the south-west of it, and being cut off by a fault at Peelplace Noddle. Between Peelplace Noddle and the River Esk the country is much faulted, the faults carrying some hæmatite, being marked on the Survey-maps as metalliferous veins, and rendering the boundary somewhat intricate.

The most noteworthy features in this area are the junction-breccia, which is developed on a large scale near Whin Crag (131 & 132), and the junction near the confluence of Scale Gill with the Esk. At the latter place the granite is somewhat coarse to within a few feet of the margin, and consists of quartz and felspar, the quartz-masses in some cases attaining several inches in diameter. Close to the margin it becomes finer in texture, and is bounded by a layer of almost pure quartz (108): this is in contact with the Borrowdales, which are much altered (see p. 68). The junction dips at a high though variable angle south-eastwards.

The boundary passes thence by Whahouse Bridge, and crosses to the southern (left) bank of the Esk, but is not well seen until Force Gill is reached, where it is at 450 feet above sea-level, thus having fallen some 900 feet from its highest point on Blaeberry How.

¹ These numerals within parentheses indicate, throughout the paper, the numbers of the localities on the Author's MS. maps and of the corresponding rock-specimens and microscopic slides, all deposited in the Museum of the Geological Department of the University of Leeds.

The actual contact in Force Gill is obscured by loose blocks which, however, include masses of the marginal varieties, from which it is assumed that the junction is a normal one and not faulted. There are in this neighbourhood many faults usually bearing ironstone, and numerous old drifts where this has been worked.

The line then passes by Low Ground to the eastern end of Devoke Water, and thence for about 2 miles in a westerly direction, being faulted along this section. It then turns sharply southwards and runs along the western flanks of Birkby Fell, Knott, Stainton Fell, Wabberthwaite Fell, Corney Fell, and Prior Park, to the head of Kinmont Beck, being obscured by Glacial deposits along much of the distance. It then bends to the west, and runs nearly parallel to the road as far as Hinning House near Bootle.

At Hinning House the boundary turns northwards and abruptly changes its character, the granite being overlain by the St. Bees Sandstone on the west, and continues to the north by Wabberthwaite to the neighbourhood of Ravenglass, where in the park of Muncaster Castle the Borrowdale rocks again emerge from beneath their covering of Trias and appear in contact with the granite.

From Ravenglass the junction may be roughly located and traced by Miteside, Irton Hall, and Mecklin Park to the foot of Wastwater, but is much obscured by drift and alluvium.

Junction with the Ennerdale Granophyre.

As already stated (p. 56) the granite comes into contact with the Ennerdale Granophyre near Eastwaite Farm. The contact is some 2000 feet in length, and extends from the foot of Wastwater to the neighbourhood of Eastwaite.

In no place could I see the actual junction, nor did I collect any junction-specimens from the loose boulders which cover the ground. A mixture of scree of a very coarse type, with Glacial deposits and torrent-gravels, the whole being covered in summer by a dense growth of bracken, renders the investigation of the boundary extremely difficult. I was, however, able to localize the line of junction within about 30 yards. At their nearest exposures the granophyre was normal in type, but the granite showed marginal features.

Both the rocks being acid in composition and unlikely, therefore, to show any marked results of thermal metamorphism, it is impossible at present to say which rock is the older; while the fact that the granite shows marginal features near the junction is consistent with either of the following views, namely:—

- (a) That the granite was intruded into the Borrowdale rocks, which already contained the granophyre in a solid condition.
- (b) That the granophyre was the later intrusion and that it came into contact with, but did not invade, the granite.

The granophyre is, as a rule, much fresher than the granite, and

this fact may perhaps, considering that the two rocks are of somewhat similar composition and similarly circumstanced as regards exposure, be taken as indicating that the granophyre is the newer rock. There is, however, at present no direct evidence as to the relative ages of the two intrusions, and I fear that this could not be gained without somewhat extensive excavations.

The Upper Surface of the Granite.

It is a fortunate circumstance that the whole of the covering of Borrowdale rocks has not been denuded from the granite, and the outliers on the summits of Blaetarn Hill and Great Barrow provide a means of determining the form of the upper surface of the intrusion. The granite shows marginal characters in both these cases, the hills being capped by Borrowdale rocks. At Great Barrow the outlier is faulted on the eastern side, and the Borrowdale rocks dip south-eastwards at an angle of 20° .

The relations of these outliers to the granite and to the general mass of the Borrowdale rocks will be made clear by a reference to the sections (figs. 1 & 2, p. 60), which are drawn to true scale.

It is interesting to note that on the crest of the granite-mass the Borrowdales are frequently reduced to a state of breccia, the interstices between the angular blocks of the lava and ash being filled by a rock identical with the marginal phase of the granite. This points to the intrusion having produced a disruptive effect along its highest part. This breccia is not seen along the flanks of the granite, although even here the volcanic rocks are penetrated for many feet by small veins of granitoid matter.

It will be noticed, on reference to the published 6-inch maps of the Geological Survey, that the Borrowdale rocks dip away from the axis of the granite-mass as though they had been elevated into a dome by its intrusion. Further evidence of the laccolitic nature of the intrusion is to be found in the fact that the granite becomes increasingly acid as its margin is approached, in some instances approximating in composition to pure quartz. The rocks into which the granite has been intruded are in every case of intermediate composition, consisting of andesitic lavas, ashes, and breccias; and, if marginal absorption of the surrounding rocks had taken place, even to a slight extent, one would have expected a higher proportion of the basic matter in the marginal varieties than in the normal granite more remote from the edge, whereas the opposite will be shown to be the case.

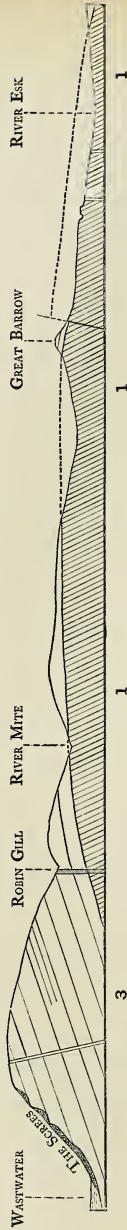
The junction-specimens which have been collected and those which have been examined in the field, show a clean-cut line of demarcation between the intrusive quartz-rock (marginal granite) and the Borrowdale rocks; and, even when examined in thin sections, the junctions are perfectly sharp, nor is there the slightest sign of any absorption of the andesites having taken place.

It is, therefore, supposed that the Borrowdale rocks were cold

N.N.W.

S.S.E.

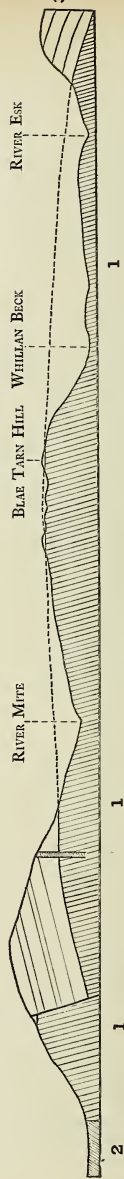
Fig. 1.—Section from Wastwater to the Woolpack in Eskdale. (Scales, horizontal & vertical : 2 inches = 1 mile.)



W.

E.

Fig. 2.—Section from Eastwaite to Boot in Eskdale. (Scales, horizontal & vertical : 2 inches = 1 mile.)



[1 = Eskdale Granite. 2 = Ennerdale Granophyre. 3 = Borrowdale Beds.]

at the time of intrusion of the granite, and that the margin of the latter was rapidly chilled, further intrusion having lifted the overlying masses and produced the dome-like structure indicated by the dips of the Borrowdale Series and of the granite-surface.

There is some slight indication of successive intrusion on the flanks of Hollinghead Bank, near Beckfoot Station on the Raven-glass & Eskdale Railway. At the points marked 160, 162, 163, 164, & 168 on my MS. maps the granite is coarse-grained and reddish in colour, while lower down the slope (that is, farther from the upper surface of the intrusion) at 88, 89, & 90, where a small quarry has been opened, it is fine-grained and grey in colour. The same fine-grained variety occurs at the quarry near Spout House (91 & 92); while above, on Hollinghead Crag, at 172 & 173, coarse granite of the normal type is to be found. The boundary of this low-level fine-grained variety is difficult to trace, owing to the profusion of fallen blocks which encumbers the slope; but, so far as I was able to determine its position, it appeared to run roughly parallel to the upper surface of the intrusion.

The small exposure of granite at Wasdale Head is of the same general type as that found in the Mitredale and Eskdale sections, and exhibits many of the same marginal phenomena, although these are not so well marked as in the case of the larger mass. In several places veins of granite may be seen penetrating the Borrowdale rocks, as, for example, in Gable Beck and near the Waterfall in Mosedale Beck.

Petrology of the Normal Granite.

There are, apart from the marginal varieties, two main types to be seen in the Eskdale Granite—one occupying the north-eastern and by far the larger portion of the main outcrop together with the smaller mass at Wasdale Head, being coarse-grained and containing a considerable quantity of muscovite and a smaller amount of biotite, usually much decomposed; and the other and far less widely distributed variety occurring in the neighbourhood of Wabberthwaite in the south-west, where it is now extensively quarried. It contains a much larger proportion of black biotite, and somewhat resembles in general appearance some of the darker-coloured varieties of the Dumfries-shire granites.

The rocks vary greatly in colour, being in some localities white to grey, while in others they are pink or even red.

Quartz is very plentiful in all the varieties, and is usually free from strain-shadows, although these occur in some parts near the great lines of fault and near the margins of the intrusion. Occasionally small flakes of muscovite occur embedded in the quartz-crystals, which also contain fluid and gas-inclusions, as described by Clifton Ward and others.

The feldspars include orthoclase, oligoclase, and a perthitic intergrowth of orthoclase and oligoclase. This perthitic inter-

growth is by far the most common feldspathic ingredient of the rock. The orthoclase apparently plays the part of host, the inclusions of plagioclase being irregular in shape but usually having their greatest dimensions in the direction of the orthodiagonal of the orthoclase, and being so arranged that their twin lamellæ (albite-law) are parallel to the clinopinacoid of the orthoclase. In many instances the plagioclase-inclusions are of sufficient size to allow of their extinction being measured; and, as the result of a large number of such measurements, using the twin striation as the index-plane, I have arrived at the conclusion that the felspar is oligoclase, and not albite (as is more usual in such intergrowths).

The presence in such large quantities of this peculiar form of perthite should serve as a valuable means of identifying doubtful cases of erratics from this source.

The micas include both muscovite and biotite, the former predominating, except in the local variety found at Wabberthwaite. The muscovite is usually quite fresh, but the biotite is often represented by chlorite, or near the great ironstone-veins by skeletons of hæmatite together with a little calcite.

The granite is remarkably free from accessory minerals, even apatite being exceedingly rare. In one specimen only I found a small quantity of tourmaline, but in several there was a little magnetite which, being associated with decomposed biotite, I conclude to be secondary.

Order of Separation of the Minerals.

In the normal granite the micas appear to have been the earliest secretion of the magma and to have separated simultaneously, being usually found in parallel intergrowth. The next secretion was apparently in most instances the oligoclase, which was followed by the perthite, orthoclase, and quartz in that order, although, as will be shown later, simultaneous separations and even reversals of some of the terms in the sequence occurred at least locally.

As a general rule, the granite is chiefly made up of quartz and perthite, the micas being present only in small quantity.

Micropegmatitic structure occurs, though rarely, and it is of a coarse-grained type very unlike that of the Ennerdale Granophyre. It usually consists of quartz and orthoclase, but instances are not wanting in which it contains perthite in place of orthoclase (6). In some instances a band of micropegmatite surrounds a crystal of orthoclase, having grown on to it in zonal fashion, so that the quartz-granules in the two portions of a Carlsbad twin are differently oriented as regards their extinction (9). This zonal arrangement of micropegmatite shows that, in this instance, its formation immediately succeeded that of the orthoclase.

Micropegmatite is usually the last secretion of a rock in which it occurs; but, in this case, the orthoclase-crystal, with its zone of micropegmatite, is surrounded by a ground-mass of quartz and felspar in a fine mosaic, although exhibiting no trace of micropegmatitic

structure. In other cases the micropegmatite is very coarse-grained, and not definitely connected with any phenocryst of felspar.

In several instances, as noted by Dr. Teall,¹ quartz is included in felspar, and this applies equally to orthoclase, perthite, and oligoclase.

An instance of quartz embedded in oligoclase is illustrated by a specimen from Mitredale Head (66). (See Pl. III, fig. 2.)

Further evidence of this abnormal order of separation is to be found in some of the fine-grained varieties near the margins of the intrusion, where phenocrysts of quartz, in one instance corroded as in the quartz-porphyrries, occur in a quartz-felspar matrix (Pl. III, fig. 3), and in the fact that the extreme margins of the laccolite, the first portions to solidify, consist of almost pure quartz. (See chemical analysis, p. 64.)

Secondary Minerals.

Hæmatite is present as a secondary mineral, and occurs in veins and patches; while in some instances it forms a fringe round the crystals of quartz and felspar, and in others impregnates crystals of muscovite where they are crossed by cracks (3).

Cracks filled with secondary quartz, in a fine mosaic, are occasionally seen to cross crystals of felspar. Chlorite is a common decomposition-product of biotite in the more weathered specimens.

Petrology of some Varieties of the Granite.

The Wabberthwaite variety (182).—This is a medium-grained dark-grey granite, in which biotite is much more plentiful than in other localities.

It consists of quartz, orthoclase (kaolinized), and a smaller quantity of perthite, with considerable quantities of biotite in a fairly fresh condition, and subordinate muscovite. The order of separation of the minerals seems to be normal.

There are also numerous veins of aplite in the Wabberthwaite Quarries.

At Stainton-Mill Dam (183) is a small exposure of a pink granitoid rock, which is unlike anything met with in other parts of the area. Under the microscope it is similar to the Wabberthwaite variety of the granite, except that it contains considerable quantities of a pale-green pleochroic amphibole.

The exposure is small and its boundaries are not seen, hence it is impossible to determine its relation to the normal variety; but, as it occurs in the midst of the granite-mass and possesses many characters in common with it, it does not seem probable that it is a separate intrusion. It may possibly be due to the inclusion and absorption of a mass of the country-rock (Borrowdale andesite) as described by Dr. R. A. Daly (Am. Journ. Sci. ser. 4, vol. xxvi, 1908, p. 19); but, if so, it is the only evidence of this action that I have seen in the district.

¹ 'British Petrography' 1888, p. 323.

The marginal varieties.—Reference has already been made to the changes in texture and composition which the granite undergoes as the margin of the intrusion is approached, and it is now proposed to describe some of the marginal varieties in greater detail.

The rock, as one would expect from the more rapid cooling which must have prevailed along the margins of the intrusion, is much finer in texture than in the more central parts. Another change, one of composition, accompanies this, a change which at first sight is not so easy of explanation. Samples of the normal Eskdale Granite were found on analysis to yield from 71·86 to 76·43 per cent. of silica, but specimens nearer the edges showed a progressive increase in the silica-percentage, until at the extreme edge of the granite in Hardrigg Gill (80) the rock contained 96·16 per cent. of silica.

In every case in which I was able to examine the actual junction of the granite with the Borrowdale rocks, these extremely acid varieties were present, though the percentage of silica was usually not so high as in the case of the Hardrigg-Gill specimen, being more commonly in the neighbourhood of 90 per cent.

ANALYSES OF THE NORMAL GRANITE AND OF THE MARGINAL SPECIMEN No. 80.

	<i>Specimen 79.</i> <i>Normal granite.</i>	<i>Specimen 80.</i> <i>Marginal variety.</i>
	per cent.	per cent.
SiO ₂	76·43	96·16
Al ₂ O ₃	13·56	1·31
Fe ₂ O ₃	0·08	0·02
FeO	0·55	0·09
MgO	0·54	0·03
CaO	0·03	trace
Na ₂ O	4·19	0·56
K ₂ O	4·72	0·30
H ₂ O (combined)	0·76	0·51
H ₂ O (free)	0·06	0·08
Totals	<u>100·92</u>	<u>99·06</u>

Marginal varieties from Robin Gill (Mitredale).—An exposure in the stream known as Robin Gill shows a fine-grained granite of a pinkish colour (51); while at (53) close to the Upper Waterfall the rock is of a felsitic texture, with small porphyritic crystals of quartz and felspar, and a few dark red patches apparently stained by hæmatite. At (54), nearer the junction, it is generally similar, but with the porphyritic constituents less conspicuous.

Specimen 53.—A fine-grained, pink, felsitic rock, with small porphyritic crystals of quartz and felspar. The ground-mass is a fine-grained mosaic of quartz and felspar, with phenocrysts of quartz, orthoclase, perthite, and oligoclase, also of biotite which has passed over into chlorite and hæmatite. The rock moreover

shows a somewhat unusual type of micropegmatitic structure. This consists of a growth of quartz about a much-decomposed crystal of oligoclase; the quartz, although very irregular in form, is apparently a single crystal, as all parts of it extinguish simultaneously; it is penetrated by smaller individuals of a feldspar, which I was unable to identify, in true micropegmatitic fashion.

Specimen 54 is a similar rock to No. 53, but rather deeper in colour and with the porphyritic elements less conspicuous. It contains a few minute flakes of muscovite which, however, appear to be secondary.

Marginal varieties from Hardrigg Gill.—The various marginal types are well exposed in Hardrigg Gill, and specimens 78, 79, 80, 80 A, 80 B, & 81 were collected in the stream, 78 being farthest from the edge of the intrusion, while 81 was an actual junction-specimen. These specimens are described somewhat fully, as they constitute the best series of the marginal varieties which have been collected.

Specimen 78.—A medium-grained granite consisting of quartz, pink feldspar, and a greyish mica.

The minerals are quartz, perthite, oligoclase, biotite, and muscovite, with apatite as an accessory. The biotite and muscovite are in parallel intergrowth, and the former has passed over into a green decomposition-product, apparently chlorite. The muscovite is present in large amount, as compared with the biotite. There are some minute particles, of a brownish-yellow mineral resembling augite, in one part of the section.

Specimen 79 (see chemical analysis, p. 64).—Less even in texture and somewhat finer-grained than 78, grey in colour, and showing larger grains of quartz and nests of mica.

The minerals are green biotite with muscovite in parallel intergrowth, perthite, oligoclase, and quartz. Threads of muscovite appear to run off from some of the larger crystals into the crystals of perthite. Micropegmatitic structure occurs, but only to a small extent.

Specimen 80 (see chemical analysis, p. 64; also Pl. III, fig. 4).—A rock of fine-grained granitic texture, but consisting almost entirely of quartz, with a few greenish veins traversing it. It is a fine-grained mosaic of quartz, with a few minute flakes of muscovite. The grains of the mosaic average 0.25 millimetre in diameter. Feldspars and biotite are absent. The specific gravity of the rock is 2.62.

Specimen 80 A.—Slightly darker in colour and coarser in texture than No. 80, but consisting of quartz with minute wisps of muscovite, and a small quantity of ilmenite apparently associated with the muscovite.

Specimen 80 B.—Similar in texture to No. 80 A, but pink in colour. It is an aggregate of quartz and perthite, with a less

quantity of oligoclase and orthoclase. Biotite is represented sparingly by decomposition-products. Muscovite is also present in small quantity.

Nos. 80, 80 A, & 80 B were all collected within a length of 20 yards, along a line at right angles to the outcrop.

Specimen 81.—This specimen shows the actual junction of the granite with a highly altered andesitic lava. The acid rock has the appearance and texture of a quartz-porphry, while the Borrowdale lava is dark grey in colour and consists largely of secondary mica.

The granite is similar in type to No. 80, but somewhat finer in texture and containing a considerable amount of felspar. It also contains phenocrysts of quartz and small nests of decomposed biotite, with a few phenocrysts of oligoclase. The quartz-phenocrysts show strain-shadows, and the rock resembles a quartz-porphry with a microgranitic base.

The Borrowdale rock consists of a very fine mosaic of quartz, with abundant minute crystals of secondary brown mica. There are also traces of larger crystals of biotite, which were proper to the rock before the intrusion of the granite. The junction between the two rocks is very sharply defined, and there is no sign of absorption having taken place. (See Pl. III, fig. 6.)

Whinscales.—The marginal zone occurs near the sheepfold at a height of 1200 feet, and is unusually thin; but there is a well-marked breccia, consisting of angular fragments of Borrowdale rocks in a granitoid matrix.

Specimen 100 A.—This is a somewhat unusual type, but I have collected it in several other parts of the area, where it always occurs just within the belt of fine-grained acid material that constitutes the extreme edge of the intrusion. It contains large and extremely thin films of biotite which coat the faces of the larger felspar-crystals, and, when seen in transverse section, look like acicular crystals. They are dark grey in colour, the remainder of the rock being pink.

Under the microscope the rock shows quartz, perthite, orthoclase, albite, and broad (but extremely thin) crystals of biotite which often exhibit the transition into chlorite. Muscovite appears to be absent. There are slight indications of micropegmatitic structure.

This rock passes gradually into the usual marginal variety, consisting of a very fine-grained aggregate of quartz, with a little orthoclase and, in this instance, a few minute flakes of biotite. The actual contact is exposed, and is seen to be perfectly sharp.

Specimen 101.—This is a specimen of the junction collected a few yards away from the sheepfold. The intrusive portion is a pink felsitic rock, consisting of a fine quartz-orthoclase mosaic with a few minute flakes of biotite. The contact is quite sharp, a large phenocryst of felspar in the Borrowdale rock being cleanly cut across.

Stony-Tarn area.—In this area (129), near the margin of the granite, occurs a granitoid rock which is distinctly porphyritic in appearance. The phenocrysts are of quartz and muscovite, and the ground-mass is a microcrystalline aggregate of quartz, felspar, muscovite, and biotite. The rock is, in fact, a quartz-porphyry.

Between Goat Crag and Whin Crag (130, 131, & 132) is a good exposure of the junction-breccia, of which fig. 3 is a photograph;

Fig. 3.—*Junction-breccia near Stony Tarn.*



[The white veins are of marginal granite, and penetrate a dark andesitic lava.]

while fig. 4 (p. 68) represents a hand-specimen of the same rock collected at 131, Pl. III, fig. 5 illustrating a thin section of the same.

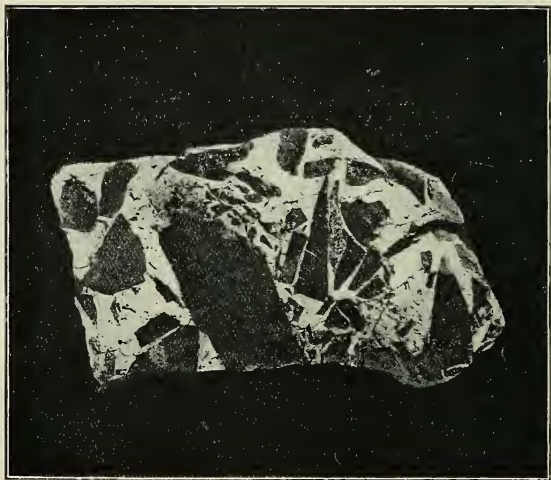
The Borrowdale rock was apparently a porphyritic andesite before alteration. The ground-mass now consists of minute flakes of brown, slightly pleochroic biotite, with a little muscovite, felspar, and quartz. The phenocrysts of pyroxene have been converted into a meshwork of pale amphibole, with a little secondary quartz. A pale pyroxene also occurs in smaller quantities. A few phenocrysts of felspar have been altered, and now contain flakes of muscovite.

The granitoid rock is a fine-grained mosaic of quartz, containing in the broader veins phenocrysts of quartz, orthoclase, and oligoclase.

Ferromagnesian minerals are represented by a very small quantity of greenish biotite, quite unlike the variety which occurs in the altered andesite.

The junction is everywhere sharp, and there is no sign of absorption of the andesite having taken place. One of the felspar-phenocrysts in this specimen is cut clean across by the contact-line.

Fig. 4.—*Hand-specimen of junction-breccia, from near Stony Tarn. (See also p. 67.)*



An examination of fig. 4 will show that the andesite-fragments in the breccia are extremely angular, in some instances possessing knife-like edges.

Many larger granite-veins penetrate the Borrowdale rocks in the same area, and consist of a pink, fine-grained, very acid granite, in which quartz and felspars are the principal constituents. Specimen 132, from one of these larger veins, shows the usual quartz-mosaic with larger crystals of perthite, quartz, oligoclase, and also phenocrysts of micropegmatite. There are narrow secondary veins of a mixture of epidote and quartz, running in various directions across many of these granite-veins.

Specimen 108 was taken from the quartz-vein which occurs at the junction of the granite with the Borrowdale rocks, one-third of a mile north of Taw House in Upper Eskdale, and already

referred to on p. 57. It consists of allotriomorphic quartz in masses at least ten times the size of those ordinarily found in the marginal mosaics. Strain-shadows are to be seen in nearly every crystal. Felspar and mica are entirely absent, and the crystals of quartz are fimbriated along their margins and closely interlocking. Furthermore, they contain numerous minute specks of a mineral possessing a high refractive index and strong double refraction, but which I have been unable to identify. In the hand-specimen this vein is precisely similar to those so commonly found in the Skiddaw Slates, and I do not consider it to be of igneous origin. It is quite different, both in appearance and in structure, from the marginal varieties of the granite.

Some Theoretical Considerations.

The fact that the granite-mass becomes more acid toward its margin is of considerable interest from a theoretical point of view.

The normal granite is more acid than the average, containing as it does about 75 per cent. of silica; and this I consider to be the explanation of the unusual marginal phenomena. It is a well-known fact that in the case of substances which form eutectic mixtures, where either of the constituents is present in excess of the quantity necessary to form the eutectic, that constituent separates out first, until the molten residue reaches eutectic proportions.

It may be considered as demonstrated that quartz and orthoclase are capable of forming an eutectic mixture, and that this eutectic plays an important part in the formation of igneous rocks, appearing as graphic and micropegmatitic structures.

That this is not the only eutectic that occurs in magmas seems to be indicated by the occurrence of similar micropegmatitic intergrowths of other minerals; and I am inclined to regard certain other intergrowths, which do not exhibit the same type of structure in their solid form, as being due to the existence of an eutectic mixture of their constituents in the magma at a certain stage of its consolidation. Thus, the parallel intergrowths of biotite with muscovite may be due to this cause; and there seems even greater reason for supposing the 'perthite', so common in the granite under consideration, to be a solidified eutectic.

The difference in the texture and structure of these various intergrowths may be explained on the hypothesis that the structure is controlled by the crystalline form of the constituents. Thus, in the parallel intergrowth above mentioned both minerals belong to the same system. In the case of perthite, where there is also a certain parallelism, the systems of the two constituents are not greatly dissimilar, being monoclinic and triclinic respectively; while in the quartz-orthoclase micropegmatite, where anything in the nature of parallelism is exceptional, the crystalline systems of the constituents are widely removed from each other as regards symmetry, being monoclinic and hexagonal.

However this may be, the fact that these intimate intergrowths occur points to a simultaneous separation of their constituents, a phenomenon which demands an explanation.

The presence in a rock of more than one pair of minerals which owe their origin and association to the solidification of an eutectic mixture, will probably be found to be due to the successive existence of a number of such mixtures in the magma at different stages of its cooling. It may well be that, as the magma cools, an eutectic association takes place, that this gives rise to the simultaneous solidification of a pair of minerals, and that at lower temperatures certain phases may detach themselves and form other eutectic associations, stable at these lower temperatures, thus breaking up the earlier one, and in their turn giving rise to other intergrowths.

It is now well known that changes in the molecular constitution of steel and alloys take place during cooling after solidification, one of these being the breaking-up of a solidified eutectic into a coarser-grained mosaic of its constituent compounds, with the obliteration of the characteristic eutectic structures. This change can be demonstrated both by cooling-curves and by microscopic examination, and the non-occurrence of micropegmatitic structure in many of the quartz-felspar ground-masses may be due to some such change. The experimental investigation of these matters is not easy. The high melting-points of the substances are in themselves a difficulty, and the extremely slow rate of cooling necessary to ensure the crystallization of the silicates renders the study of cooling-curves and volume-changes extremely difficult, if not well-nigh impossible.

To return to the question of the acid margins of the granite. It is, of course, well known that most batholiths, especially those of basic composition, vary considerably in composition as between their central and peripheral parts, the edges of the intrusion being usually more basic than the interior.

In the case of the Eskdale Granite, it is my opinion that the reversal of the usual distribution, namely, the occurrence of the more acid rock on the periphery and the more basic in the interior, is due to the magma as a whole having been more acid than some eutectic, probably that of quartz and orthoclase, and the consequent primary separation of quartz until the eutectic proportions were reached, at all events locally.

The case for the early separation of quartz from the magma does not rest on the marginal phenomena alone: for, as has already been stated (p. 63), the rock contains examples of quartz-crystals enclosed in phenocrysts of oligoclase and other feldspars; while the presence of phenocrysts, similar to those that occur in the quartz-porphyrries, in some of the finer-grained varieties, points in the same direction. One cannot, however, expect a complete solution of this problem without further experimental work.

III. THE SMALL INTRUSIONS NEAR PEERS GILL. (Fig. 5, p. 72.)

Peers Gill is a steep-sided gorge excavated in the Borrowdale Series, partly along a line of fault and partly along an ironstone-vein. It lies in the angle between Lingmell and Great End, and drains the northern slope of Scafell Pikes.

In the neighbourhood of the gorge numerous exposures of intrusive rocks are seen, varying somewhat in texture, but resembling each other in chemical composition, and connected by a number of dykes. Somewhat similar rocks also occur on Lingmell Crag, and at Bursting Knotts on the opposite side of Upper Wasdale.

Specimen 232.—The rock from Bursting Knotts, a small exposure immediately south of the path leading from Wasdale Head to Sty-Head Pass, is dark grey in colour and holocrystalline in texture, the feldspars showing signs of a change to epidote. In section, the texture is seen to be granitic, and the rock contains quartz, orthoclase, andesine, a large quantity of brown biotite (now somewhat chloritized), and a considerable quantity of epidote.

Of the rocks from the foot of Peers Gill, that from 233A is a pink felsitic rock, with a microcrystalline ground-mass consisting for the most part of feldspar, but with some quartz. It contains many phenocrysts of andesine and an occasional phenocryst of orthoclase, there being also some epidote and a little hæmatite.

Specimen 233B is a somewhat similar rock, but more basic in composition. It contains numerous pseudomorphs in chlorite and epidote, apparently after a pyroxene.

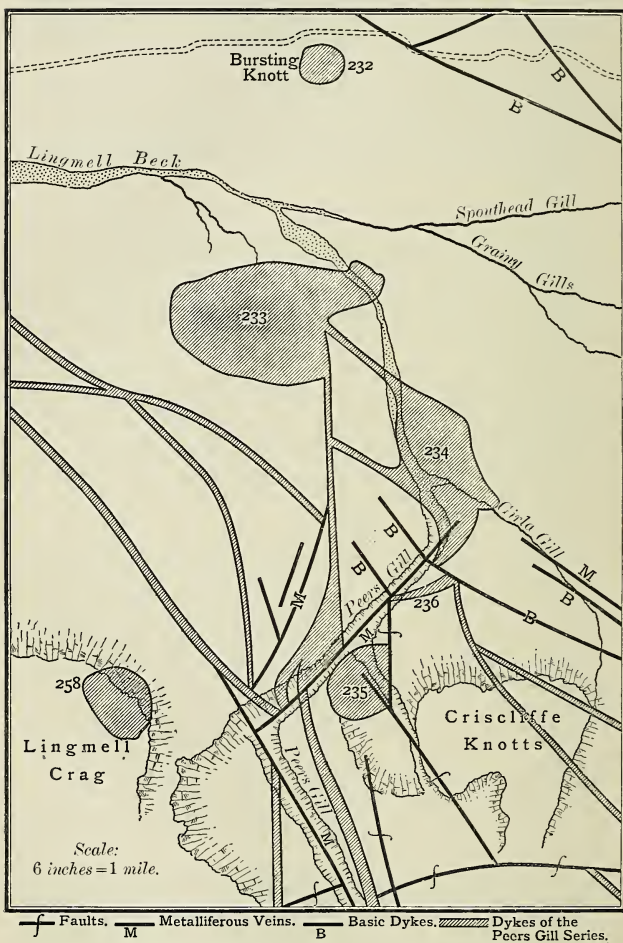
Specimen 233C.—This seems to be a highly-altered diorite, and consists very largely of chlorite and secondary biotite, with considerable quantities of feldspar playing the part of ground-mass.

Specimen 234.—From the junction of Peers Gill and Girta Gill comes a greyish hemicrystalline rock with a mottled appearance. The ground-mass is very fine-grained, and consists of small clear feldspars and quartz. There are numerous phenocrysts of an oligoclase-andesine, which frequently show zonal structure. Deep brown and strongly pleochroic biotite is also abundant. The biotite is fresh, except on the edges of the crystals, where a change to chlorite has set in. There are also numerous pseudomorphs apparently following pyroxene, and consisting of a mixture of calcite, magnetite, and biotite. The rock is an altered andesite.

The rock from Lingmell Crag is similar, both in texture and in composition, to Specimen 232.

These rocks show a community of character among themselves, but are petrologically quite unlike anything in the areas occupied by the Eskdale Granite, either in the main exposure or in that at Wasdale Head. It is assumed in the Horizontal Section (Sheet 114) of the Geological Survey, that one of these, namely that on Lingmell

Fig. 5.—Map showing the dykes and other intrusions near Peers Gill.



[For 'Bursting Knott,' read 'Bursting Knotts.']

Crag, is an offshoot of the Eskdale Granite; but, as it will be shown that dykes belonging to this series are cut and displaced by those connected with the granite, and as the rocks themselves are chemically and mineralogically unlike the Eskdale Granite, it seems more probable that all these smaller intrusions are independent of, and older than, that rock.

IV. THE DYKES.

An inspection of the 1-inch maps of the Geological Survey reveals a very large number of dykes intersecting the Borrowdale rocks of the district.

These dykes are divided into three groups, namely, felsite, quartz-felsite, and basalt; and it is apparently assumed by the Geological Survey (judging from the published sections) that the felsite and quartz-felsite dykes are connected with the granite-intrusion, the basic dykes being much later, cutting and in some instances displacing the acid intrusions.

The quartz-felsites appear to be represented by a single large dyke running from Great Bank near Eskdale Green (at which locality it occurs as a vein in the granite itself) by way of the south-eastern slope of the Screes, where it enters the Borrowdale Series, to Wasdale Hall at the head of Wastwater. Thence it passes across Lingmell Gill and the north-western flank of Lingmell to the granite-exposure at Wasdale Head, which it appears to penetrate. On the opposite side of the granite, it can be traced from the neighbourhood of Burnthwaite up the side of Eskdale Fell, and across the summit of Kirk Fell to Bayscar Slack, at the foot of Kirkfell Crag. This appears to be the only dyke that is undoubtedly connected with the granite-mass, with which it agrees petrologically.

The 'felsite'-dykes occur mainly in three areas:—

- (1) On Yewbarrow and High Fell.
- (2) Near Allen Crag and Angle Tarn.
- (3) Along a line from Kirkfell Crag on the north-west, by way of Peers Gill and Little Narrow Cove, on Scafell Pikes, to Bowfell on the south-east.

The Quartz-Felsite Dyke.

This dyke, which is, in my opinion, the only one that is connected with the Eskdale Granite, consists of a reddish holocrystalline rock of the quartz-porphry group. It exhibits large and well-marked porphyritic crystals of felspar and quartz, with a smaller quantity of mica, in a microgranitic ground-mass. Some of the larger orthoclase-phencrysts exhibit distinct zonal structure and a tendency to change into epidote.

The Dykes on Yewbarrow and High Fell.

Specimen 201, collected from a dyke on the left bank of Over Beck, between Overbeck Bridge and Bowerdale Farm, consists of a dark-grey fine-grained rock, much jointed, and presenting the appearance of a rhyolite. The ground-mass is felsitic, with marked flow-structure, and is considerably stained by hæmatite. There are phenocrysts of felspar, but they are so much decomposed as to render it impossible to identify them with certainty: their habit, however, suggests that of andesine. The rock also contains pseudomorphs after pyroxene or amphibole, or after both.

A little higher up the stream the dyke is shifted about a sixth of a mile to the north-east by a fault, and then follows the course of Over Beck to the junction of Brimfull Beck with that stream. Specimens collected at 203, 204, 205, 206, & 207 along the course of the dyke, were found to be similar in constitution to that just described.

Specimen 208, from a dyke crossing Brimfull Beck, is of similar character.

Specimen 209, from another dyke a little higher up the same stream, is a pink felsite which is non-porphyrific. It consists of a fine mosaic of felspar and quartz, with small wisps of chlorite, probably after biotite.

Specimen 210, from the dyke which forms the waterfall in Nether Beck, about 100 yards above Netherbeck Bridge, is very similar to 209.

Specimens 211 to 214, from the dykes so numbered on my MS. map, consist of a highly-decomposed pink felsite with marked spherulitic structure, and containing much secondary epidote and chlorite.

Specimens 215 to 224 form a network of dykes on the high ground between Nether Beck and Over Beck. They possess the same general characters as Nos. 211 to 214 just described, but vary somewhat as regards the coarseness of their texture.

Specimens 228 to 231 are of pink felsite, with spherulitic structure similar to that exhibited by Nos. 215 to 224.

The above form a group of dykes closely related to each other, and possessing marked similarity of composition.

The Dykes near Allen Crag and Angle Tarn.

In this group are included Nos. 237 to 242, which are all andesitic in composition, and bear a general similarity both to one another and to the andesitic lavas of the Borrowdale Series, with which they are associated. Specimen 237 will serve as an example.

Specimen 237, collected close to the edge of a small tarn

north of Allen Crag (B.M. 2185.4), is a grey andesite. The ground-mass is principally felspar and chlorite, and the phenocrysts are chiefly of andesine. There are also large pseudomorphs in calcite and chlorite after pyroxene, and smaller ones after biotite.

The Dykes of Group 3. (Figs. 5 & 6, pp. 72 & 76.)
(Nos. 236 & 249 to 256.)

There are numerous dykes connected with the intrusions at Bursting Knotts and Peers Gill, and extending north-westwards on the one hand to Kirkfell Crag, and south-eastwards on the other to the neighbourhood of Angle Tarn, by way of Little Narrow Cove. Descriptions of several varieties of rocks from this series follow.

Specimen 236.—A pink felsitic rock, much streaked with dark-green matter. The ground-mass is cryptocrystalline, and there are many porphyritic crystals of andesine, also pseudomorphs in epidote after an amphibole or a pyroxene. Numerous veins of epidote and chlorite traverse the rock, imparting to it the streaked appearance noted in the hand-specimen. Evidently, the rock is an altered andesite. The dykes in Little Narrow Cove show some slight variation in character, but, on the whole, are of andesitic type.

Specimen 250 A is a fine-grained rock of granitic texture, and consists of quartz, white felspar, and streaks of dark-green matter. Microscopic examination reveals orthoclase and plagioclase, with large quantities of chlorite after biotite and of epidote.

Specimen 250 B is greenish in colour, and shows marked porphyritic structure, felspar and dark-green pseudomorphs being conspicuous. The ground-mass is felsitic, and there are large phenocrysts of andesine, with a smaller quantity of orthoclase and a few crystals of quartz which are corroded. Chlorite and epidote, apparently after biotite, are also present in considerable quantity. The rock moreover contains numerous small needles of apatite.

Specimens 251 to 256 are similar as regards their general characters to No. 250 B, although they are somewhat finer in texture.

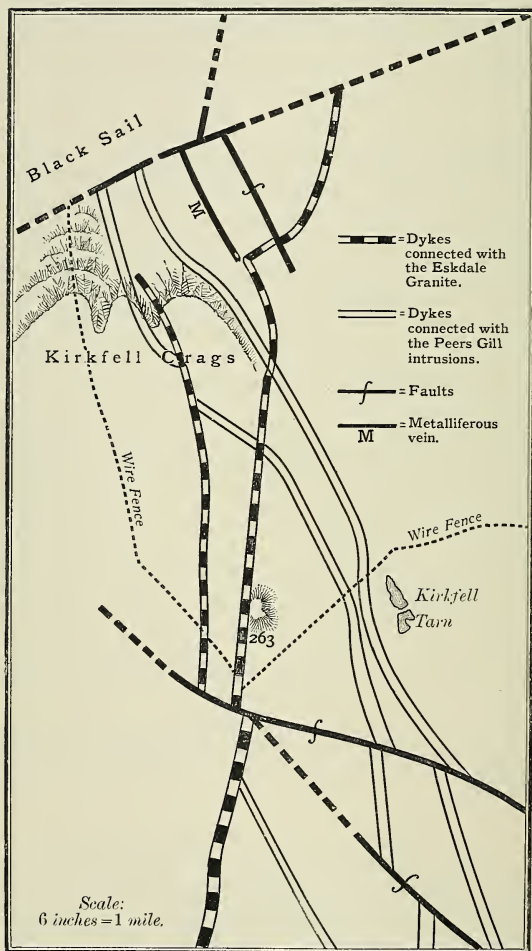
Specimen 249, at the foot of Skilling Crag, is distinctly andesitic in character. It contains much epidote, with oligoclase and andesine. There is no quartz, and the ground-mass is cryptocrystalline.

V. GENERAL RELATIONS OF THE INTRUSIVE ROCKS.

The dykes on Kirkfell Crag consist of two sets (fig. 6, p. 76)—one with a north-west to south-east trend, and the other running in a north-east to south-west direction.

Of these, the former consists of a group of two main dykes, which, though cut and displaced by several faults, can be traced by Kirk Fell and Ill Gill to Gable Beck, where they form the two

Fig. 6.—Map showing the dykes on Kirk Fell.



waterfalls, and thence to Flass Knotts and Peers Gill, and one or two minor offshoots of these. These dykes are certainly connected with the intrusions of 'bastard granite' at Peers Gill, and form a continuation of the two main dykes in Little Narrow Cove.

The other set consists of the great dyke of granite-porphry already mentioned (p. 73) as connected with the Eskdale Granite, and a smaller offshoot of the same.

Reference to fig. 6 (p. 76) will show that the dykes connected with the Peers-Gill intrusions are cut, and in one instance displaced, by the dyke of granite-porphry, indicating that this is the younger intrusion.

Thus, there appear to be five well-marked groups of intrusions in this district:—

- (a) The andesitic dykes in the neighbourhood of Allen Crag and Angle Tarn.
- (b) The dykes of the spherulitic and felsitic group on Yewbarrow and High Fell.
- (c) The dioritic ('bastard granite') bosses of Peers Gill, Lingmell Crag and Bursting Knotts, with their associated dykes.
- (d) The Eskdale Granite, with the granite-porphry dyke running from Great Bank to Wasdale Head and thence to Kirkfell Crag.
- (e) The dolerite-dykes, having a general north-west to south-east trend.

The dykes of series (a) bear a very strong petrological resemblance to the Borrowdale volcanic rocks into which they were intruded. Furthermore, they are weathered to much the same extent, and have developed the same secondary minerals, among which epidote is conspicuous. They appear to me to be of Borrowdale age, and roughly contemporaneous with the lavas and ashes among which they are intruded.

The spherulitic series (b) is more acid in type; but here again the amount of alteration is very great, and the rocks are similar to many of the rhyolitic lavas found in the upper part of the Borrowdale Series. These also are considered to be of Borrowdale age, although probably somewhat later than the andesitic series (a).

The rocks of the dioritic group (c), though less altered than those of groups (a) & (b), are still far from fresh; and, furthermore, the changes which have taken place in them are similar to those that have affected the Borrowdale lavas, a notable feature being the great development of secondary epidote. These may well be the holocrystalline and hypabyssal equivalents of the Borrowdale lavas, and I am of opinion that they also are of Ordovician age.

My chief reason for thinking that these rocks have had a separate origin from the Eskdale Granite is the marked contrast in composition which they show to that rock. As I have already pointed out, the principal feldspars in the granite are orthoclase and perthite (orthoclase-oligoclase); but, in the smaller intrusions of Peers Gill, orthoclase is uncommon and perthite wholly absent, while oligoclase-andesine and andesine, unknown in the granite, are present in

considerable quantity. Further, in the minor intrusions biotite is present in large quantity, while in the granite muscovite is the dominant mica. There are also pseudomorphs after either a pyroxene or an amphibole, both of which minerals are absent from the normal granite of both Eskdale and Wasdale Head.

(*d*) The Eskdale and Wasdale Granites and their associated dyke are much more acid than any of the other rocks hitherto mentioned, and they show comparatively little alteration, with the exception of that due to weathering along the great lines of dislocation occupied by the ironstone-veins. They are undoubtedly intrusive in the Borrowdale Series, and the western boundary of the main intrusion, as shown on the maps of the Geological Survey and as confirmed in the field, very strongly suggests that they are pre-Triassic. Unfortunately, no clear exposure of the junction with the Trias could be found; but the similarity of the relation which the Triassic outcrop bears to the granite and to the Borrowdale rocks is strong evidence of the existence of the granite before the Triassic Period. It seems probable that this intrusion belongs to the Devonian Period, as does the neighbouring granite of Shap, which, with the exception of its large phenocrysts of orthoclase, is not dissimilar to some of the varieties of the Eskdale Granite (as, for example, the Wabberthwaite variety).

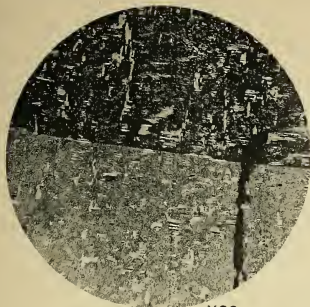
(*e*) The basic intrusions have not yet been examined, except in one or two instances where they come into proximity to the granite. They are, however, undoubtedly the latest intrusions in the area, and may be seen cutting and displacing any of the others with which they come into contact. Although basic in composition and containing olivine, they are much less altered than any of the other intrusive rocks. They may well be connected with the great Tertiary basic flows of Antrim, as has, I believe, been suggested by Mr. Harker.

My thanks are due to Mr. R. H. Rastall for information respecting the neighbouring intrusion of granophyre; to Mr. Cosmo Johns for many facts recently added to our knowledge of the structure of alloys; and to Messrs. C. G. Jackson & G. V. Wilson for analyses of rock-specimens.

EXPLANATION OF PLATE III.

- Fig. 1. Crystal of perthite (orthoclase-oligoclase) in Eskdale Granite. Slide 78, magnified 23 diameters. See pp. 61-62.
2. Quartz embedded in oligoclase, Eskdale Granite. Slide 66, magnified 23 diameters. See p. 63.
3. Phenocryst of quartz in the marginal variety of the Eskdale Granite. Slide 7, magnified 12 diameters. See p. 63.
4. Quartz-mosaic from the margin of the Eskdale Granite. Slide 80, magnified 23 diameters. See pp. 63 & 65.
5. Junction-breccia from near Stony Tarn. Slide 131, magnified 16 diameters. See pp. 67-68.
6. Junction of granite (*a*) and altered Borrowdale lava (*b*), near Stony Tarn. Slide 81, magnified 23 diameters, See p. 66.

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X23

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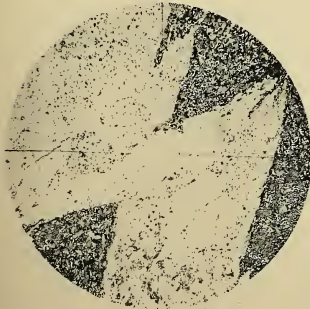
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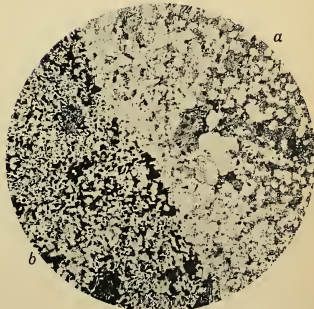
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A. R. Derryhouse, Photo-micro.

Bemrose, Collo., Derby.

IGNEOUS ROCKS FROM ESKDALE.

DISCUSSION.

Dr. TEALL said that the paper was evidently an important one, but that, in view of the demonstration which was to follow, he would only make one remark: the fact that the Eskdale Granite had a very acid margin appeared to furnish another illustration of the general law, that those substances which crystallize first from the average magma—an acid one in this case—tend to concentrate in the cooler parts.

Mr. BARROW, referring to the use of the word 'eutectic' by the Author, suggested that the highly quartzose material, on the outer margin of the intrusion, was really an eutectic compound of low consolidation-point, formed of quartz and water, the latter probably in the form of vapour or steam.

Mr. J. F. N. GREEN said that the Author's work in disentangling the relative ages of these intrusions would be of the greatest value to others working in the Lake District. So far as the southern edge of the Eskdale mass was concerned, he could confirm the Author's observations; but he considered that, as the relations of the faults on the map shown seemed to indicate, the Eskdale Granite was older than the main crust-movements, whereas the Shap Granite was younger.

Dr. J. W. EVANS called attention to the similarity between the inclusions of quartz in the feldspars, and those occurring in the rocks allied to granulites described by him from the Rio Madeira, and by Prof. Weinschenk from Ceylon.

Mr. COSMO JOHNS commented on the value of the Author's observations, and said that the very acidic margin might be explained by assuming that the excess substance had separated from some eutectic; yet, there was the possible alternative that two liquid phases, one much more acid than the other, existed in the magma and had partly separated, owing to their difference in specific gravity, before intrusion took place. He thought the Author's explanation of the presence of structurally free quartz and feldspar, where micropegmatite would be expected, most important. It had been demonstrated experimentally in the case of certain alloys, that if the cooling of the mass be arrested at the point where the eutectic separates out, for a sufficiently long period, the two constituents would segregate and be structurally free. That particular structure, once thought to be characteristic of the eutectic mixture, was therefore but the accident of a particular rate of cooling, and this rate might differ for each eutectic. The usual absence of the structure from rocks where it might be expected to occur could be explained: it was its occasional presence that created the difficulty. The Author's conclusion that the temperature of the mass when intruded was comparatively low seemed well founded. It did not appear that any satisfactory determination of the fusion-point of quartz had been made. The high temperatures given for the fusion-point of silica referred to tridymite. The temperature at which the transformation of quartz into tridymite occurred was

much lower, and he thought that the fusion-point of quartz would be low. He considered that the neglect of experimenters to recognize the quartz-tridymite transformation-point might explain their difficulty in determining the true fusion-point of micropegmatite.

The AUTHOR thanked Dr. Teall for his complimentary remarks upon the paper, and Mr. Barrow for his suggestion that an eutectic of quartz and water might have played an important part in the history of the rock; and said that, if this were the case, the difficulty raised by another speaker with regard to the high temperature of the magma at the time of intrusion might be removed. He also expressed his full accord with the views of Mr. Cosmo Johns on the subject of eutectics, and acknowledged many valuable suggestions which he had from time to time received from him. With regard to the question of two liquid phases, the Author pointed out that evidence of the existence of such phases was difficult to obtain; but that, if they could be shown to have existed, many difficulties might be removed.

He welcomed Mr. Green's remarks as to the age of the intrusion, and pointed out that the only direct evidence on this subject was that the granite was intrusive in Ordovician rocks and apparently covered unconformably by the Trias. The dyke of quartz-porphry on the Screes was indeed displaced by faults, but these probably did not belong to the great pre-Devonian movement, as their lines were frequently occupied by doleritic dykes which were the latest intrusions in the area and were probably of Tertiary age.

In conclusion, the Author thanked the Fellows for their cordial reception of his paper.